Manufactured Housing Research Alliance

Attic Ventilation Design Strategies for Manufactured Homes

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EXECUTIVE SUMMARY

A literature search and review was conducted to investigate attic ventilation design strategies for manufactured homes. The findings of the literature review were debated among, and analyzed by, a Steering Committee of industry representatives. The literature reveals that ventilation of attic and cathedral ceiling air cavities have been recommended building practices for four reasons: moisture control, energy conservation, asphalt shingle durability, and ice dam prevention. U.S. building codes, including the HUD-code, require attic ventilation in most cases for all climates. The practice of ventilating all attics is based on research conducted in cold climates. Studies in other areas suggest that optimal attic system design may vary significantly by climate.

The research concluded that homes in the hot, humid climate may benefit the most from alternate attic design strategies, including an unvented attic design. A program of testing is proposed to evaluate various attic design strategies including an unvented attic constructed simply by eliminating the ventilation openings, a sealed attic constructed by intentionally sealing the roof cavity, an attic with insulation in the roof plane, and a conventionally constructed vented attic. The end product of this proposed work would be one or more attic designs for hot, humid climates with improved moisture control performance characteristics.

2

INTRODUCTION

The intent of this project is to investigate attic ventilation strategies that may improve the performance of manufactured homes. Up-to-date, more complete information on the performance of various attic designs for manufactured homes will enable designers to make better informed decisions and provide a foundation upon which to base future changes to the HUD standards.

This research project is not in response to specific moisture-related failures. The purpose of this document is to identify research that needs to be undertaken, that will form the basis of specific design recommendations. While cost is always part of the equation, it is not the driving force behind this research. Economics will enter into the process as specific designs are evaluated.

A committee was formed to guide this research project and to provide input from a variety of perspectives. Committee members were drawn from home manufacturers, ventilation equipment and roofing materials manufacturers, third party regulatory agencies (DAPIAs), academia, and the U.S. Department of Housing and Urban Development. These stakeholders discussed and debated the issues surrounding this research in a series of conference calls, individual communications, and responses to drafts of this document. The document that follows is largely based on the scientific literature reviewed during the course of the project. The end-product of this phase of the work is a defined research program assessing specific attic designs that may vary by climate.

The report begins with a brief overview of attic ventilation, its purpose and evolution, in Section 2. Section 3 contains a summary of design options by climate. The heart of this section is a table of attic design options. Section 4 contains recommendations for future research. The appendices contain a synopsis of the current regulations for HUD-code homes (Appendix A), detailed recommendations of the literature by climate (Appendix B), and a summary literature review (Appendix C).

2.1 BACKGROUND

Airflow through homes, and its impact on building performance, is one of the least well understood building science phenomenon. For a manufactured home, the air space can be broadly segregated into three regions: the living space, the attic cavity, and the crawlspace (or basement). This paper focuses on the attic airspace (the attic is the space between the ceiling and the roof). Since the 1940s conventional wisdom has maintained that for proper moisture control in the attic cavity, attics should be ventilated continuously with outside air. In addition to moisture control, other arguments for ventilating attics were subsequently made, including energy conservation, mitigation of high roofing surface temperatures, and prevention of ice dams. While the initial research that established attic ventilation as a standard practice was conducted exclusively in cold and simulated-cold climates, the practice (and building codes to enforce the practice) spread throughout the U.S. into all climate regions. This paper makes the case that attic design in manufactured homes should not be a one-size-fits-all solution and must be examined individually for each climate type.

Attic ventilation has been effective in controlling moisture problems in predominately cold climates where the objective is to maintain cold attic temperatures in winter to avoid ice dams created by melting snow and to vent moisture that moves from the conditioned space into the attic. However, attic ventilation may cause moisture problems in other climates. For example, in hot, humid climates humid outdoor air that comes in contact with cold surfaces in the attic may condense – particularly if low interior temperatures are maintained during summer. Recent research suggests that in hot, humid areas, the best approach to avoiding moisture condensation in attics may be to keep the moisture out of the attic altogether by sealing the attic from the outdoors.

Furthermore, complex ceiling designs in new homes make air sealing between the attic cavity and living space more difficult; and resulting incomplete attic air barriers often allow humid air to contact cooled surfaces potentially causing moisture-related problems.

Ceilings in new homes are often a series of horizontal, vertical, and sloped planes, with mechanical chases, recessed lights, fireplace flues, and penetrations for plumbing, electrical, and space conditioning equipment. In reality, it is often impractical to try to maintain continuity of the air or vapor retarder at all of these locations. Air-tight recessed lights rated for insulation contact, foam sealing of penetrations, and full-depth blown insulation to cover the variations in ceiling plane can help to alleviate the problems, but at significant added cost. The most cost-effective location for moisture and infiltration control and insulation may in fact be at the roof plane rather than the interior ceiling plane, thus providing additional support for sealed, cathedralized attic strategies.

The Manufactured Housing Construction and Safety Standards (MHCSS) requires that attics in all double-section and shingled, single-section homes be ventilated. As noted above, this may not be the common practice for other housing types in many locations.

The published literature relating to attic ventilation suggests that unvented attics can work in all climates if designed and constructed properly. Unvented attics provide the most advantage over vented attics in humid climates. In fact, attic ventilation became a standard practice based solely on research conducted in the 1930s and 1940s in cold and simulated-cold climates. No scientific claims have ever been made for venting attics in hot/humid climates.

Most of the available published research on attic ventilation has focused on site-built homes or generic computer models, however a number of significant studies on HUD-code homes have also been conducted. Some of the most convincing research supporting unvented attics was conducted in part or exclusively on HUD-code homes (5, 7, 32, 33)[1]. This research is summarized in Appendix C of the report.

[1] Numbers in parentheses refer to literature referenced and summarized in Appendix C.

3

SUMMARY OF DESIGN OPTIONS BY CLIMATE

Table 1 summarizes attic design recommendations from a number of authors (see Appendix C) by climate for four climates and six distinct design options as distilled from the literature. (The design options are unique combinations of ventilation, insulation location and duct location as indicated on the table.) Two configurations that differ from current practice (dark shaded cells) are recommended as the best candidates for further research based on the literature and on the practicality of integrating them with manufactured home construction. Four additional cells (light shading) are also recommended for future research.

The literature reveals that ventilation of attic and cathedral ceiling air cavities have been recommended building practices for four reasons: moisture control, energy conservation, asphalt shingle durability, and ice dam prevention. U.S. building codes, including the HUD-code, require attic ventilation in most cases for all climates. The practice of ventilating all attics is based on research conducted in cold climates. Studies in other areas suggest that optimal attic system design may vary significantly by climate.

Sealing the attic from ventilation, with the insulation either in the ceiling or the roof plane, may provide advantages from a moisture control standpoint in hot/humid and cool/humid climates. Sealing the attic in hot/dry climates does not provide any significant advantages for HUD-code homes unless it provides for improved insulation of ductwork located in the attic.

Elimination of ventilation leads to higher attic air and surface temperatures. The effect of these higher temperatures on asphalt shingle durability is unknown, although certain shingle manufacturers void or reduce their warranties if their shingles are installed over unvented roofs.

Control of attic moisture in mixed and cold climates can best be achieved through: 1) reduction of humidity in the living space during winter; 2) a well-sealed ceiling air barrier and vapor retarder; 3) attic ventilation. The amount of moisture removed via attic ventilation in cold climates in winter is limited, as cold air has little moisture-carrying capacity. However, the degree to which a reduction in humidity in the home and air movement across the ceiling plane can be achieved is uncertain, so ventilation of the attic provides a relief valve should moisture get into the attic. It also keeps the attic cooler in summer, potentially providing energy benefits.

Recognizing that optimal attic design, particularly as it relates to moisture control, is highly dependant on the climate in which the home is located, it is logical to analyze the design options separately for each climate type. In ***Issues Relating to Venting of Attics and Cathedral Ceilings***, Rose and TenWolde (33) used three climates: cold inland; wet, cold, coastal; and warm, humid. ASHRAE discusses moisture control issues in three climates: heating climates; mixed or temperate (which includes hot and dry climates); and warm, humid. Lstiburek (13) has established five climates for their analysis of thermal and moisture related building issues: Hot-humid; mixed-humid (which includes the cool/humid northwest region); hot-dry/mixed-dry; cold; and severe cold (which is primarily located in Canada). For this analysis, four climate types are used: hot/humid, hot/dry, cool/humid (including temperate coastal zones) and mixed and cold (see Figure 1). Significant research on attic performance has been done in hot/dry climates as well, so this climate was differentiated on the map.

Table 1 cross-references each climate type with each of six attic design options. The variables in the design options are as follows: (Y/N) indicated whether or not the attic is ventilated, the location of the roof insulation (along the roof plane or at the ceiling barrier) and the location of the ducts (attics or underfloor). The bottom two rows in the table show the relationship of each design to the HUD Manufactured Housing Construction and Safety Standards—24 CFR 3280 (MHCSS) and the International Residential Code 2000.

As indicated in Table 1, the literature points to the opportunity for developing alternative attic designs in the hot/humid and cool/humid climates. Moisture problems are more common in these regions than in drier climates, and the benefits of ventilating the attic are less clearly established in the literature than for colder climates. Homes located in the hot/dry climate do not experience significant moisture problems and so there is little incentive to conduct attic research for manufactured homes in this region. Homes in mixed and cold climates also have less of a reason to consider unvented attics, and more reasons to maintain the current venting practices. While there may be advantages to unvented attics in the cool/humid climate, there is less concern that condensation and air leakage will cause building moisture problems during cooler periods in this climate and a desire to maintain drying potential in the face of leaks and other exterior entry of water in these often rainy regions make unvented attics in the cool/humid climate less attractive. Therefore, between cool/humid and hot/humid areas, unvented or sealed attics[2] may perform best in hot/humid climates and is the best candidate region for further research.

[2] The term "unvented attic" indicates a conventionally built attic with the exception that vent are not installed. A "sealed" attic indicates an attic in which vents are not installed, plus where special measures have been taken to seal all air passages between the attic and the exterior.

Table 1. Matrix of Attic Design Options – with recommendations of several authors as distilled from the literature

Design Option	**1**	**2**	**3**	**4**	**5**	**6**
Ventilated attic	Yes	Yes	No	No	No	No
Insulation location	Ceiling	Ceiling	Ceiling	Ceiling	Roof plane	Roof plane
Duct location	Floor	Attic	Floor	Attic	Floor	Attic
HOT/HUMID	***Current practice. Not recommended***	***Current practice in the deep south. Not recommended***		*Strongly Recommended for further research*		*Recommended for further research. Manufacturing considerations may limit its use*
HOT/DRY	*Current practice. Acceptable if duct is well insulated.*	*Acceptable practice if duct is well insulated*	*Acceptable, but no advantage over Option 1*	*Acceptable, but no advantage over Option 2*	*Not recommended. No advantage over Option 1*	*Acceptable for energy conservation purposes*
COOL/HUMID	***Current practice. Not recommended***	***Current practice. Not recommended***		*Recommended for further research*		*Recommended for further research. Manufacturing considerations may limits its use*
MIXED AND COLD	*Current practice. Acceptable if additional humidity control measures are employed.*	*Acceptable practice if duct is well insulated and used with humidity control measures.*	*Not recommended*	*Not recommended*	*Acceptable if designed and installed properly*	*Acceptable if designed and installed properly*
MHCSS	Required design for most homes (with exception of duct location)	Required design for most homes (with exception of duct location)	Acceptable design for single-section homes with metal roofs	Acceptable design for single-section homes with metal roofs	Acceptable design for single-section homes with metal roofs but not practical	Acceptable design for single-section homes with metal roofs but not practical
IRC 2000	Ventilation required	Ventilation required	Not accepted	Not accepted	Not accepted	Not accepted

Notes:

1. Entries in bold suggest practices that are not recommended based on the literature and MHRA Committee review.
2. Light-shaded boxes are combinations of conditions that are worthy of subsequent research.
3. Dark-shaded boxes are combinations of conditions where follow up research is strongly recommended.
4. See Appendix B for an expanded description of recommendations in the literature by design option and Appendix C for an literature summary
5. This table refers to both single and multi-section manufactured homes unless otherwise noted

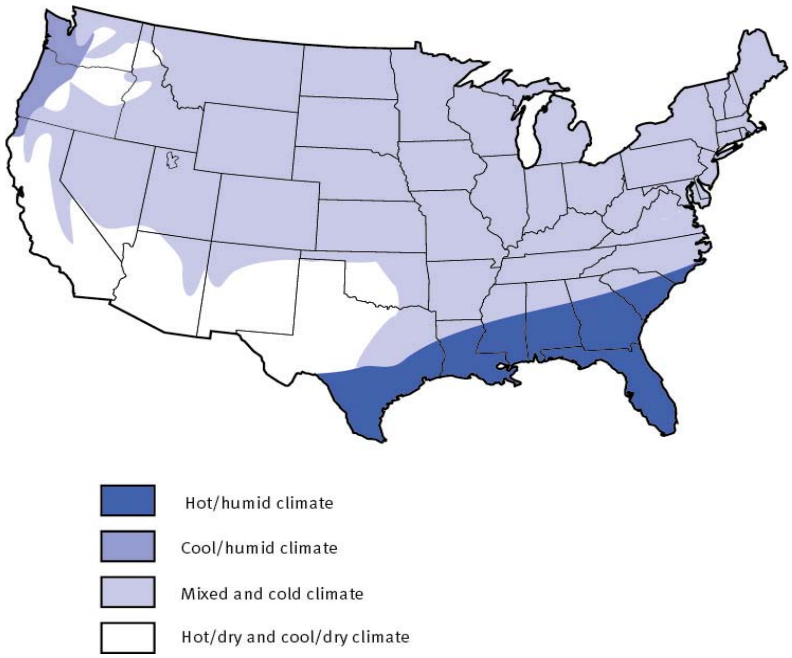

Figure 1. Map of Climate Regions[3]

[3] The map used here is a slightly modified version of the one on page 2.1 of the MHRA publication ***Moisture Problems in Manufactured Homes: Understanding Their Causes and Finding Solutions***. This map may not be an accurate reflection of regions for attic ventilation purposes. One component of the research proposed in Section IV is to define the precise regions of these climate types. Therefore this map should be thought of as indicative of the regional coverage, but not useful in defining precise boundaries.

4

RECOMMENDATIONS FOR FUTURE RESEARCH

4.1 RESEARCH STRATEGY

Research is suggested that investigates the benefits and barriers to the use of unvented attics for all types of homes in the hot/humid climate. The program would develop commercially viable unvented manufactured home attic designs, evaluate those designs under conditions typical of the extremes associated with the hot/humid climate and quantify the costs and benefits associated with the designs. Success in this initial work would be followed by efforts to help bring unvented designs to market, such as removing regulatory barriers and a robust program of dissemination and outreach.

In accomplishing the goals for this next phase of the research, several important questions will need to be addressed, including the following:

1. To what extent must the attic be sealed to function properly as a moisture control strategy?
2. What are the critical construction practices needed to achieve a unvented attic?
3. What is the capacity of unvented attics in hot humid climates to expel moisture should it enter?
4. What is the cost of unvented attic designs and what are the barriers to the manufacture and installation of such designs?
5. What is the effect of higher temperatures on materials and components used in unvented roof designs, such as asphalt shingle durability?
6. What should be the boundaries of those climate regions for which unvented designs would be recommended?
7. Can active strategies, such as pressurizing the attic with outside air as a component of a whole house ventilation strategy, contribute to a viable unvented attic design for hot/humid climates? This ventilation strategy is currently used in some homes. Its effectiveness and optimal design are questions for subsequent investigations.

4.2 SCOPE OF WORK

A program consisting of the following elements will be developed to answer the building science questions raised above. The goal of these elements will be to develop proof-of-concept design(s) and demonstrate their feasibility for manufactured housing.

4.2.1 Develop designs and specifications for attic designs.

One or more unvented attic designs (with insulation in the ceiling and the roof plane) will be developed for the hot/humid climate. The hot/humid climate is selected because it offers the largest and clearest potential benefit for individual homes and has the potential to positively impact a large number of homes. The attic design will consider all relevant performance variables, including moisture, energy, and material durability. It will also take into account the cost and buildability issues associated with the manufacturing environment and be applicable to all major home configurations on the market (i.e. single or double-section, cathedral or flat ceiling, etc.). The designs will be based on the literature, practical experience, consultation with manufacturers to determine cost and buildability, and the theory of moisture and vapor behavior in attics.

4.2.2 Construct and test prototypes of the attic design or designs developed above

Testing will include monitoring of moisture, thermal performance, and surface temperature levels. Components, such as air barriers and attic pressurization systems, if appropriate, will be tested to determine their effectiveness and to analyze how their performance may be improved.

4.2.3 Quantify climactic divisions

Define the limits of the hot/humid climate for which the designs would be acceptable. There may be overlapping regions where a number of designs are acceptable, rather than a distinct boundary dividing areas where one design is acceptable and another is not. Regional recommendations that are flexible in this way not only recognize the realities of climate variation, but will enable plants that ship across climate "boundaries" to standardize their production. The ASHRAE Humid and Fringe Climate Map will be used as the starting point for this investigation.

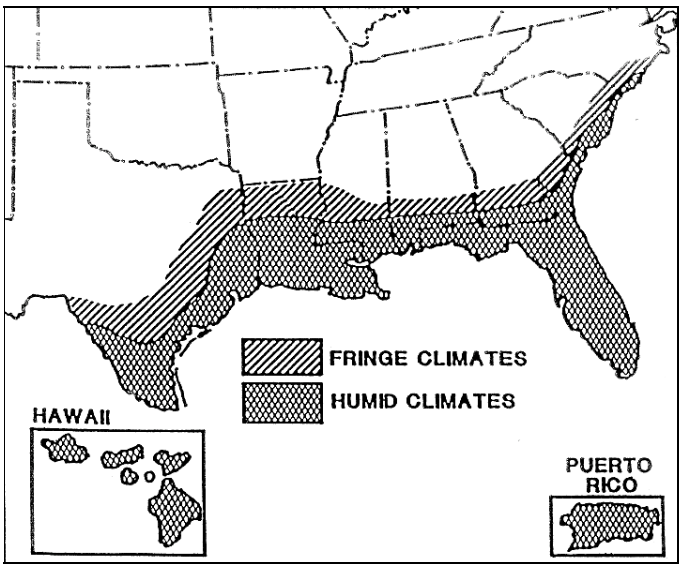

Figure 2. ASHRAE Humid and Fringe Climate Map[4]

4.3 CONSTRUCT AND TEST PROTOTYPES

The testing program will focus on constructing and monitoring one or more prototype manufactured homes while inducing stressful conditions that are hypothesized to cause moisture problems in attics and ceilings.

4.3.1 The test home(s)

One or more double-section homes will be built and set in the hot/humid climate region – most likely along the gulf coast of Florida or Louisiana. Alternatively, individual roof sections may be built for study in one of several roof research facilities. These facilities will have the ability to control interior and exterior conditions and precisely measure heat and moisture transfer. Four attic types will be studied this way. If multiple attic types are incorporated into a single test home, each section will be isolated from the next as necessary to minimize interstitial thermal and vapor movement. Both near

[4] 2001 ASHRAE Fundamentals Handbook

and longer term solutions will be investigated. Two designs will incorporate insulation in the ceiling, rather than re-locating it to the roof plane, as that is more consistent with current manufactured housing construction practices and will most likely result in lower costs and less disruption to the existing manufacturing process. One design will incorporate insulation in the roof plane as a more dramatic shift from current practice. The diagrams below show flat ceilings, however the test roofs may utilize cathedralized roof designs, which are common in manufactured homes.

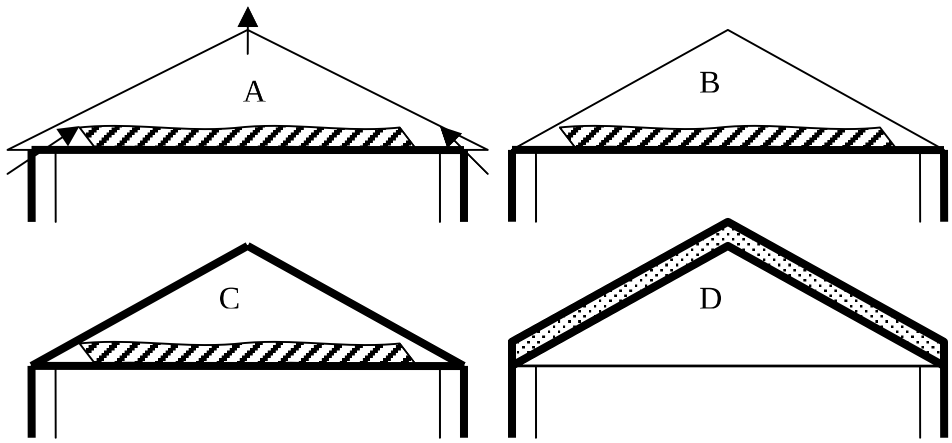

Figure 3. Attic configurations

a. Attic A will be a current practice ventilated attic. This attic is the benchmark to which the others will be compared.

b. Attic B will be an unvented attic constructed by simply not installing vents into the attic cavity.

c. Attic C will be a sealed attic, constructed by eliminating vents and paying special attention to creating an air and vapor retarder at the roofline and the ceiling line, as well as the ends of the roof cavity. While the literature suggests that an attic cavity constructed without vents to the exterior may be advantageous from a moisture standpoint in hot/humid climates, it does not quantify the tightness that would be required of the air and/or vapor barrier separating the attic from the outside. Comparing attics B and C will permit the evaluation of the importance of this parameter.

d. Attic D will have an insulated roof deck without ventilation of the roof cavity. There will be an air and vapor retarder located in the roof plane. This design represents a greater jump in construction technology. Commercialization would be farther in the future, but with larger potential benefits. One downside of this configuration (as shown) is it increases the conditioned space without increasing the livable space.

   If full-scale test homes are used, they will be built according to the waiver recently issued by HUD permitting a wall vapor barrier to be installed on the exterior side of the wall insulation rather than the interior of the walls in humid climates. Attics A, B, and C will have insulation above the ceiling, will have no ceiling vapor barrier, but will have a ceiling air barrier. Materials will be selected based on their prevalence in typical HUD-code construction, i.e. fiberglass or cellulose insulation, dark color asphalt roofing shingles, OSB roof sheathing, wood roof trusses, etc. Attic D will have an air/vapor barrier integral with the roof deck. It will be constructed of commonly used materials, except where technical requirements demand materials not typically used for manufactured housing roof construction. The ducts will be located in either the attic cavity or under the floor, based on the system deemed most common for manufactured homes in the hot/humid climate. This will be determined by surveying the manufacturers that supply the bulk of the homes to this region. Alternatively, both configurations could be examined.

After the home(s) are set, measurements of shell and duct leakage will be taken to ensure that these parameters are representative of typical manufactured home performance, as determined by recent studies conducted by MHRA and others. Additional measurements will be taken in each attic cavity to record the air leakage across the ceiling air barrier and the overall leakage of the attic cavity.

4.3.2 Stressing the attic

The home(s) will be monitored over the course of a full cooling season (May through October), during which time they will be subjected to variations in interior conditions that represent the extremes of what may be experienced in a typical home, and are theorized to cause moisture problems. Each of these conditions will be established and measured over periods sufficient to reach equilibrium or observe a number of diurnal cycles.

a. High pressures in the living space relative to the attic, created by the air handler operation

b. Negative pressures in the living space relative to the outside and the attic, created by simulating high duct leakage when the air handler is operating

c. Low interior thermostat set point

d. High indoor humidity created by a humidifier to simulate occupant activities such as bathing, and operation of whole-house ventilation systems in humid climates

e. Combinations of these variables will also be explored, such as high interior pressure and low temperature

4.3.3 Monitoring

The following parameters will be monitored in each of the test attic cavities on a continual basis over the course of the project:

a. Surface temperatures and moisture content of materials in the attic, including the sheathing and framing members

b. Attic humidity, air temperature and pressure

c. Living space air temperature, atmospheric pressure and humidity

d. Outside air temperature, pressure, humidity, wind speed and direction

4.3.4 Using the data

The information gathered from the test homes will be used to inform the attic design process specifically for manufactured homes in three ways:

a. Evaluate the relative effectiveness of each design in handling the conditions hypothesized to cause moisture problems in attics. How robust is each design compared to the others? Which one experienced the lowest attic humidity, least propensity to experience condensation, lowest temperatures, etc. This evaluation will help establish or debunk the theory that sealed or unvented attics have superior moisture performance in hot/humid climates.

b. Establish measurements of relative temperatures experienced by shingles and sheathing materials. How much hotter do these materials get, and over what periods of time, on unvented attics compared to vented attics? This will inform future research into the durability of asphalt shingles by establishing benchmark temperatures.

c. The data collected may be used to validate simulation tools so that the results can be extrapolated to other sets of conditions (e.g., climates and home configurations). The simulation tools will aid in developing an appropriate climate map for attic design recommendations.

4.4 RESEARCH PRODUCTS

1. **Attic design(s)**

   Develop one or more attic designs for hot/humid climates, including detailed design drawings and specifications and cost estimates.

2. **Climate map**

   Propose a climate map for use with the proposed attic designs.

3. **Evaluation/documentation**

   Document the design process and supporting data. Prepare a report including performance data based on testing results and a buildability analysis based on feedback from manufacturing plants.

4.5 FUTURE TASKS

Should the design concept be proved through the above work, the following tasks will be considered as elements of a program of rapid dissemination.

1. **Regulatory**

   Make recommendations for changes to the HUD-code through the then current standards update process.

2. **Commercialization**

   Assist the industry in commercializing the new attic designs, including working out bugs in manufacturing and design processes, and producing educational materials for the industry and consumers.

3. **Dissemination**

   Promote the spread of the above referenced information through articles in trade publications, web-based materials, and dedicated reports and technical bulletins.

APPENDICES

A

CURRENT REGULATIONS AND PRACTICE

A.1 MANUFACTURED HOME CONSTRUCTION AND SAFETY STANDARDS

Section 3280.504(c) of the HUD-code requires that attics and roof cavities be vented. Interestingly, single-section homes with metal roofs and no sheathing or underlayment are exempted from this requirement if air leakage paths between the living space and attic are sealed. Presumably, the rationale behind this regulation is that the metal roofing material will not be damaged by increased temperature and there is no sheathing to be degraded by high moisture content or condensation. The question of whether it is realistic to expect a tightly sealed air barrier in practice in unanswered. The text of the code is as follows:

> *"(c) Attic or roof ventilation. (1)Attic and roof cavities shall be vented in accordance with one of the following:*
>
> *(i) A minimum free ventilation area of not less than 1/300 of the attic or roof cavity floor area. At least 50 percent of the required free ventilation area shall be provided by ventilators located in the upper portion of the space to be ventilated. At least 40 percent shall be provided by eave, soffit or low gable vents. The location and spacing of the vent openings and ventilators shall provide cross-ventilation to the entire attic or roof cavity space. A clear air passage space having a minimum height of 1 inch shall be provided between the top of the insulation and the roof sheathing or roof covering. Baffles or other means shall be provided where needed to ensure the 1 inch height of the clear air passage space is maintained.*
>
> *(ii) A mechanical attic or roof ventilation system may be installed instead of providing the free ventilation area when the mechanical system provides a minimum air change rate of 0.02 cubic feet per minute (cfm) per sq. ft. of attic floor area. Intake and exhaust vents shall be located so as to provide air movement throughout space.*
>
> *(2) Single section manufactured homes constructed with metal roofs and having no sheathing or underlayment installed, are not required to be provided with attic or roof cavity ventilation provided that the air leakage paths from the living space to the roof cavity created by electrical outlets, electrical junctions, electrical cable penetrations, plumbing penetrations, flue pipe penetrations and exhaust vent penetrations are sealed.*
>
> *(3) Parallel membrane roof section of a closed cell type construction are not required to be ventilated.*
>
> *(4) The vents provided for ventilating attics and roof cavities shall be designed to resist entry of rain and insects."*

A.2 ASHRAE'S POSITION

The 2001 ASHRAE Fundamentals Handbook (chapter 24) addresses attic ventilation for heating and hot/humid climates with respect to moisture, temperature, ice dams, and energy consumption.

For heating climates, in part it says the following about moisture:

> *"In heating climates, attic ventilation usually provides a measure of protection from excessive moisture accumulation in the roof sheathing. If indoor humidity is high and humid outdoor air leaks into the attic, attic vents by themselves may not prevent moisture accumulation.*
>
> *Moisture control in attics in heating climates depends primarily on (1) maintaining lower indoor humidity levels during cold weather, (2) assuring maintainable airtightness and vapor resistance in the ceiling, and (3) attic ventilation (NRC 1963)."*[5]

Addressing attic temperature and shingle degradation concerns in heating climates, it says in part:

> *"A ventilated attic is cooler in the summer than an unventilated attic, and ventilation can reduce the temperature of shingles during daylight hours. Asphalt shingle manufacturers encourage ventilation as a prescriptive practice (ARMA 1997)."*
>
> *"It is not clear that attic air temperature reduction is a significant factor in extending the service life of shingles (TenWolde and Rose 1999), since the long term studies on the temperature effects on shingle service life are incomplete."*[6]

Regarding ice dams in heating climates, it says in part:

> *"Reducing heat loss into the attic by effective insulation, air leakage control, and avoidance of heat sources such as uninsulated or leaky heating ducts in the attic, possibly coupled with ventilation, is a positive way of reducing ice dams and moisture damage (Fugler 1999)."*[7]

With respect to cathedral ceilings, ASHRAE acknowledges that ventilating cathedral ceilings can be difficult in practice and may degrade the performance of the insulation. The Handbook states that "With careful attention to design for air- and vapor-tightness, unvented cathedral ceilings can be expected to perform satisfactorily in cold heating climates."

For hot/humid climates, ASHRAE's makes the following attic design recommendations:

> *"Common sense suggests that venting with relatively humid outdoor air means higher levels of moisture in the attic or cathedral ceiling."*
>
> *As with other climates, a ventilated attic in a warm, humid climate is noticeably cooler in the summer than an unventilated attic. Beal and Chandra (1995) found that venting can greatly affect the temperature differences across the ceiling."*[8]

These last two statements present the designer with a tradeoff: seal the attic for the moisture benefits and risk poorer thermal performance, or ventilate the attic to lower its temperature and increase the risk of moisture problems.

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[5] 2001 ASHRAE Fundamentals Handbook, 24.6
[6] ibid.
[7] ibid.
[8] 2001 ASHRAE Fundamentals Handbook, 24.8

A.3 COMMON ATTIC DESIGN PRACTICES FOR MANUFACTURED HOMES

Most homes are constructed with passive ridge and soffit vents as per the HUD-code. Some homes employ mechanical ventilation of the attic. Insulation is installed on the attic floor over the gypsum board and truss bottom chords. In certain regions, particularly Florida and other parts of the Deep South, the ducts are sometimes located in the attic under the insulation; however most homes have ducts located under the floor. The floor insulation wraps under the duct and encompasses it within the thermal envelope of these homes. Vapor barriers are normally installed in the ceiling (warm side of the insulation) in U_o-value Zones 2 and 3, but omitted in Zone 1 (a region that includes the hot/humid areas).

As per the HUD-code, single-section homes with metal roofs and no sheathing or underlayment are normally constructed without attic ventilation. Air paths between living area and attic are sealed in these homes, although the performance of these seals is unknown.

A.4 SUMMARY

While most building codes, including the HUD-code, maintain the requirements for attic ventilation regardless of climate, there is an increasing realization, as evidenced by ASHRAE's recommendations, that it may be appropriate to consider the local climate when determining attic ventilation requirements.

B

RECOMMENDATIONS BY CLIMATE

Recognizing that optimal attic design, particularly as it relates to moisture control, is dependant on the climate in which the home is located, it is logical to analyze the design options separately for each climate type. Four climate types have been identified hot/humid, hot/dry, cool/humid (which includes temperate coastal zones) and mixed and cold. For each of these climates, a literature summary, design parameters and an analysis of six design options is presented.

Four building performance issues are affected by attic design. These issues are: 1) condensation, 2) heating and cooling energy use, 3) roofing material condition, and 4) ice damming. Condensation in the attic can lead to degradation of wood sheathing and structural members, ceiling stains and leaks. Unnecessarily high heating and cooling loads will lead to greater energy costs. Degradation of roofing materials can lead to a shorter lifespan for the roofing and potentially to leaks and their associated consequences. Ice dams can also lead to leaks as well as hazardous ice build-up on eaves and gutters. The performance of a specific attic design strategy varies with respect to each these issues.

Also important in selecting an attic design is its constructability and cost. The design must be compatible with the production environment and processes employed in the manufacturing plants, as well as the field. While these factors are touched on here, a full analysis must await future work on those designs which are selected for further research based on the above-stated performance criteria.

B.1 HOT/HUMID CLIMATE

B.1.1 Summary

The scientific literature that directly addresses the subject of attic ventilation in hot/humid climates is consistent in its conclusion that ventilation is not an effective strategy for removal of moisture (5, 13, 14, 15, 23, 24, 30, 33). Most studies express the opinion that attic ventilation is not desirable in this climate because more moisture is brought into the attic cavity by introduction of humid outside air than is expelled through ventilation (5, 14, 15, 23, 24). The studies that established attic ventilation as a standard practice were conducted in the 1930s and 1940s in cold or simulated-cold climates (20, 33).

Specific issues related to attic ventilation in homes placed in hot, humid climate:

- Vapor barriers should not be installed on the interior of assemblies, as this will trap moisture in the insulation in humid climates where the conditioned living space has a lower humidity than the attic air (7, 13).
- Asphalt shingles can be used with unvented roofs in hot/humid climates (15, 23, 26, 33). Although it’s been suggested that a temperature increase on the order of 3-5 degrees F may somewhat reduce the service life of asphalt shingles, there is no data to support this. Additionally, the color of the shingle has a significant effect on shingle temperature. This question merits further investigation – what is the effect of increased sheathing temperature on asphalt shingle durability and lifespan? At what temperature and duration is the effect on

the shingle significant? At least some major shingle manufacturer warrantees would be voided if installed over unventilated roofs.

- An unvented cathedral ceiling is a viable option in hot/humid climates (14, 26, 33).
- Cooling loads in homes with well-insulated ceilings are not significantly reduced by employing attic ventilation (20, 24, 25, 33). When cooling load calculations account for the moisture load caused by humid air entering the attic via ventilation (and leaking into the living space), the load can actually be higher than for homes with higher-temperature unvented attics (3, 20, 24).

B.1.2 Design Parameters

The goals to be achieved through changes in the ventilation strategy and suggested approaches for hot/humid climates as derived from the literature references are summarized below in approximate order of effectiveness.

Prevent condensation in attic that might lead to moisture problems – a major issue in this climate.

a. Eliminate the ceiling vapor retarder. It will cause moisture problems as moisture is trapped on the attic side (7, 13).

b. Seal the attic to eliminate ventilation and keep humid outside air out of the attic space (3, 5, 13, 14, 15, 23, 24).

c. Place insulation in roof plane to incorporate the attic into the thermal envelope, thereby conditioning and dehumidifying the attic air (14, 26, 33).

Minimize energy consumed by heat transfer through attic space or ductwork in attic

a. Use light colored (high reflectivity) roofing material to mitigate attic heat build-up (particularly with cathedralized attics) (17, 18).

b. Locate ducts in well insulated attics instead of uninsulated attics where energy efficiency will be reduced through conductive or convective losses (18, 22, 24, 25, 26, 28). The attic location may also improve cooling efficiency and comfort in warm climates, as cool air coming from above may be a more efficient delivery mechanism.

c. Maintain a well sealed air barrier in the ceiling to prevent conditioned air from escaping into the unconditioned attic.

d. Maintain a lower thermal gradient across the ceiling insulation by ventilating and thereby cooling the attic. This will have a minor cooling affect (20, 24, 25, 33), but will increase latent cooling load if the ceiling air barrier is leaky (3, 33). This is a more effective strategy for poorly insulated (<R14) ceilings (29).

Maintain durability of roofing and sheathing materials. Degradation of roofing materials can lead to higher replacement cost as well as leaks and their associated problems.

a. Use non asphalt-based roofing such as tile or metal (15, 22).

b. Use light colored asphalt shingles that will maintain a lower service temperature (33).

c. Ventilate the attic or cathedral roof to carry away heat from underside of sheathing. This may have some beneficial effect, however it is unproven and most likely minor (15, 23, 26, 33).

B.1.3 Design Options

Option 1: Ventilated attic with insulation in ceiling. Ducts under floor. No vapor retarder in ceiling.

This configuration is the standard practice for attic design in multiple-section manufactured homes, with the exception that some manufacturers use vapor retarder paint on their ceilings . The literature strongly suggests that ventilating the attic in this climate is not advisable from a moisture control or energy control standpoint, although it may provide some benefit by prolonging asphalt shingle lifespan.

Hypothesis	**Literature**
Moisture is allowed to leave the home via ventilation air movement out of attic.	This is contradicted by the literature. No scientific sources have been found to support this hypothesis. More moisture enters the attic, and potentially the home, with humid outside air, than is vented from the attic. (3, 5, 13, 14, 15, 23, 24)
Attic ventilation reduces interior temperature of attic.	Supported by the literature. A reduction of approximately 15 to 20 degrees F can be expected during peak cooling season with typical 1 to 150 or 1 to 300 ventilation ratios (26).
Lower attic temperature reduces cooling load on home.	For homes with a well insulated ceiling, the load increase is minor (20, 24, 25, 33). The load may actually increase with increased latent cooling load of more humid air entering the attic and leaking into the living space (3, 20, 24). Cool attic temperatures are of more benefit where ceilings are poorly insulated (<R14) (29).
Lower attic temperature keeps shingles cool.	The literature estimates a reduction of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

Option 2: Ventilated attic with insulation in ceiling. Duct in attic covered with insulation. No vapor retarder in ceiling.

This configuration is common practice for multiple-section manufactured homes in Florida and other regions of the Deep South, with the exception that some manufacturers use vapor retarder paint on their ceilings . The literature strongly suggests that ventilating the attic in this climate is not advisable from a moisture control or energy control standpoint, although it may provide some benefit by prolonging asphalt shingle lifespan. If not well insulated, the cool duct may precipitate condensation on its surface.

Hypothesis	**Literature**
Moisture is allowed to leave the home via ventilation air movement out of attic.	This is contradicted by the literature. No scientific sources have been found to support this hypothesis. More moisture enters the attic, and potentially the home, with humid outside air, than is vented from the attic. (3, 5, 13, 14, 15, 23, 24)
Attic ventilation reduces interior temperature of attic.	Supported by the literature. A reduction of approximately 15 to 20 degrees F can be expected during peak cooling season with typical 1 to 150 or 1 to 300 ventilation ratios (26).
Lower attic temperature reduces cooling load on home.	For homes with a well insulated ceiling, the load increase is minor (20, 24, 25, 33). The load may actually increase with

Hypothesis	Literature
reduces cooling load on home.	increased latent cooling load of more humid air entering the attic and leaking into the living space (3, 20, 24). Cool attic temperatures are of more benefit where ceilings are poorly insulated (<R14) (29).
Duct is under insulation and therefore less prone to condensation and energy loss.	The effectiveness of this insulation coverage should be investigated.
Lower attic temperature keeps shingles cool.	The literature estimates a reduction of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

Option 3: Sealed (unvented) attic with insulation in ceiling. Ducts under floor. No vapor retarder in ceiling.

The literature suggests that eliminating the ventilation from the standard attic design practice will reduce moisture levels in the attic and adverse effects to energy use and shingle lifespan will be minimal. This configuration has the potential to lower costs and improve performance in hot/humid climates, and should be explored further.

Hypothesis	Literature
Humid outside air cannot enter attic and contribute to moisture level.	Supported by the literature (3, 5, 13, 14, 15, 23, 24)
Moisture in the attic will migrate through the ceiling insulation and dry towards the interior.	Supported by the literature (7, 13)
Cooling load not detrimentally impacted by higher temperature in attic (assuming adequate ceiling insulation).	For home with a well insulated ceiling, the load increase is minor (20, 24, 25, 33). The load may actually increase with increased latent cooling load of more humid air entering the attic and leaking into the living space (3, 20, 24). Cool attic temperatures are of more benefit where ceilings are poorly insulated (<R14) (29).
Minor increase in shingle temperature is not a significant disadvantage of this design.	The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Using lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

Option 4: Sealed (unvented) attic with insulation in ceiling. Ducts in attic. No vapor retarder in ceiling.

The literature suggests that eliminating ventilation from current attic design practice will reduce moisture levels in the attic and adverse effects on energy use and shingle lifespan will be minimal. This configuration has the potential to lower costs and improve performance in hot/humid climates where ducts are already placed in the attic, and should be explored further. This configuration is an improvement over option 3 from an energy standpoint, if ducts will be better insulated and further removed from ground moisture than the would be in the floor.

Hypothesis	**Literature**
Humid outside air cannot enter the attic and contribute to increasing the moisture level.	Supported by the literature (3, 5, 13, 14, 15, 23, 24)
Moisture in attic insulation will migrate through ceiling insulation and dry towards interior.	Supported by the literature (7, 13)
The cooling load is not detrimentally impacted by higher temperatures in the attic (assuming adequate ceiling insulation).	For home with a well insulated ceiling, the load increase is minor (20, 24, 25, 33). The load may actually increase more from the increased latent cooling load of more humid air entering the attic via ventilation and leaking into living space (3, 20, 24). Cool attic temperatures are of more benefit where ceilings are poorly insulated (<R14) (29).
Minor increase in shingle temperature is not a significant disadvantage of this design.	The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Using lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

Option 5: Sealed (unvented) attic with insulation following the roof plane. Ducts under floor.

The literature suggests that this design is beneficial from a moisture standpoint.

Hypothesis	**Literature**
Humid outside air cannot enter the attic and contribute to increasing the moisture level.	Supported by the literature (3, 5, 13, 14, 15, 23, 24).
Conditioning of attic air (now that it is included inside the thermal envelope) will keep its relative humidity level down and minimize the opportunity for condensation.	Supported by the literature (14, 26, 33).
Minor increase in shingle temperature is not a significant disadvantage of this design.	The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Using lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

Option 6: Sealed (unvented) attic with insulation following the roof plane. Ducts in attic.

The literature suggests that this design is beneficial from a moisture and energy standpoint.

Hypothesis	Literature
Humid outside air cannot enter the attic and contribute to increasing the moisture level.	Supported by the literature (3, 5, 13, 14, 15, 23, 24).
Conditioning of attic air (now that it is included inside the thermal envelope) will keep its relative humidity level down and minimize the opportunity for condensation.	Supported by the literature (14, 26, 33).
Energy performance of the home will be enhanced as ducts will not conduct or leak air to the outside, nor will ducts draw moist air inside from the crawlspace.	Supported by the literature (18, 22, 24, 25, 26, 28).
Minor increase in shingle temperature is not a significant disadvantage of this design.	The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Using lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

B.2 HOT/DRY CLIMATE

B.2.1 Summary

Ventilation of attics should be optional (13, 15), but a vapor barrier should not be used (13). Energy savings attributed to cathedralized attics in hot/dry climates are primarily due to enclosing of cooling ducts within the conditioned space (based on research conducted on site-built homes) (26).

B.2.2 Design Parameters

The goals to be achieved through changes in the ventilation strategy and suggested approaches for hot/dry climates as derived from the literature references are summarized below in approximate order of effectiveness.

Prevent condensation in attic that might lead to moisture problems – not a significant problem in this climate.

a. Keep attic temperature warm enough to prevent surfaces from falling below dew point temperature – via insulation in roof plane instead of attic floor.

b. Ventilate attic to dilute moisture once it passes into the attic (13).

Minimize energy consumed as a result of heat transfer through attic space or ductwork in attic.

a. Use light colored (high reflectivity) roofing material to mitigate attic heat build-up (particularly with cathedralized attics) (17, 18).

b. Locate ducts in well insulated attic spaces (18, 22, 24, 25, 26, 28) rather than in floors. This may also improve cooling efficiency and comfort in warm climates. Cool air coming from above may be a more efficient delivery mechanism.

c. Create a well sealed air barrier in the ceiling to prevent conditioned air from escaping into unconditioned attic.

d. Maintain a lower thermal gradient across the ceiling insulation by ventilating and thereby cooling the attic. This will have a minor cooling affect (20, 24, 25, 33) and is more significant for poorly insulated (<R14) ceilings (29).

Maintain durability of roofing and sheathing materials. Degradation of roofing materials can lead to higher replacement cost as well as leaks and their associated problems.

a. Use non asphalt-based roofing such as tile or metal (15, 22).

b. Use light colored (high reflectivity) asphalt shingles to maintain a lower service temperature (33).

c. Ventilate the attic or cathedral ceiling to carry away heat from underside of sheathing. This may have some benefit, however its effect on shingle temperature is unproven and most likely minor (15, 23, 26, 33).

B.2.3 Design Options

Option 1: Ventilated attic with insulation on attic floor. Ducts under floor. No vapor retarder in ceiling.

This configuration is the standard practice for attic design in multiple-section manufactured homes, with the exception that some manufacturers use vapor retarder paint on their ceilings . Ventilation may provide some benefit by prolonging asphalt shingle lifespan and lowering thermal gradient across ceiling insulation, and providing an outlet for moisture should it enter the attic.

Hypothesis	**Literature**
Moisture that infiltrates the attic from the living area is allowed to leave the home via ventilation air movement out of attic.	Supported by the literature as a secondary method of mitigating attic moisture levels (5, 7, 20, 33).
Attic ventilation reduces the interior temperature of attic.	Supported by the literature. A reduction of approximately 15 to 20 degrees F can be expected during peak cooling season with typical 1 to 150 or 1 to 300 ventilation ratios (26).
Lower attic temperature reduces the cooling load on the home.	For home with a well insulated ceiling, the load increase is minor (20, 24, 25, 33). Cool attic temperatures are of more significance for poorly insulated (<R14) ceilings (29).
Lower attic temperature keeps shingles cool.	The literature estimates a reduction of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

Option 2: Ventilated attic with insulation in ceiling. Duct in attic covered with insulation. No vapor retarder in ceiling.

Ventilation may provide some benefit by prolonging asphalt shingle lifespan and lowering thermal gradient across ceiling insulation, as well as providing an outlet for moisture should it enter the attic. Locating ducts in the attic will result in energy savings only if they are better insulated than they would be in the floor.

Hypothesis	Literature
Moisture that infiltrates attic from living area is allowed to leave the home via ventilation air movement out of attic.	Supported by the literature as a secondary method of mitigating attic condensation (5, 7, 20, 33).
Attic ventilation reduces the interior temperature of attic.	Supported by the literature. A reduction of approximately 15 to 20 degrees F can be expected during peak cooling season with typical 1 to 150 or 1 to 300 ventilation ratios (26).
Lower attic temperature keeps shingles cool.	The literature estimates a reduction of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).
Lower attic temperature reduces the cooling load on the home.	For home with a well insulated ceiling, the load increase is minor (20, 24, 25, 33). Cool attic temperatures are of more significance for poorly insulated (<R14) ceilings (29).
Duct is under insulation and therefore less prone to condensation and energy loss.	The effectiveness of this insulation coverage should be investigated.

Option 3: Sealed (unvented) attic with insulation in ceiling. Ducts in floor. No vapor retarder in ceiling.

There is no advantage to sealing the attic in a dry climate, so this configuration has no advantage over option 2, except to eliminate the cost of ventilating.

Option 4: Sealed (unvented) attic with insulation in ceiling. Ducts in attic. No vapor retarder in ceiling.

There is no advantage to sealing the attic in a dry climate, so this configuration has no advantage over option 2, except to eliminate the cost of ventilating.

Option 5: Sealed (unvented) attic with insulation following the roof plane. Ducts in floor. No vapor retarder in ceiling.

There is no advantage to sealing the attic in a dry climate, so this configuration has no advantage over option 2, except to eliminate the cost of ventilating.

Option 6: Sealed (unvented) attic with insulation following the roof plane. Ducts in attic. No vapor retarder in ceiling.

Placing ducts fully within the thermal envelope of the home in a hot climate has been demonstrated to save significant amounts of energy. Condensation is less of a concern with this configuration as the attic is within the conditioned space.

Hypothesis	Literature
Energy performance of the home will be enhanced as ducts will not conduct or leak air to the outside.	Supported by the literature (18, 22, 24, 25, 26, 28)
Minor increase in shingle temperature is not a significant disadvantage of this design.	The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Using lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

B.3 COOL/HUMID CLIMATE

B.3.1 Summary

Ventilation of attics and cathedral ceilings is not desirable in this climate because more moisture is brought into the attic cavity by introduction of humid outside air than is expelled through ventilation (3, 8, 33). One field study found no correlation between attic ventilation and sheathing moisture levels in temperate coastal climates (1).

B.3.2 Design Parameters

The goals to be achieved through changes in the ventilation strategy and suggested approaches for cool/humid climates as derived from the literature references are summarized below in approximate order of effectiveness.

Prevent condensation in attic that might lead to moisture problems - major issue in this climate.

a. Keep humid outside air out of the attic by sealing the attic (1, 3, 8, 15, 33).

b. Place insulation in roof plane to incorporate attic into thermal envelope, thereby conditioning and dehumidifying the attic air.

Minimize energy consumed by heat transfer through attic space or ductwork in attic.

a. Construct a well sealed air barrier in ceiling to prevent conditioned air from escaping into unconditioned attic. Achieving and maintaining the necessary level of sealing may be difficult throughout the manufactured home production transportation and installation processes.

Maintain durability of roofing and sheathing materials. Degradation of roofing materials can lead to higher replacement cost as well as leaks and their associated problems.

a. Same approaches as other climates (non-asphalt or lighter colored roofing, or attic ventilation), but impact is less significant since high temperatures and intense sunlight are less extreme and of shorter duration in these climates.

Prevent ice dams, which can lead to hazardous conditions as well as leaks and their associated problems.

a. Construct a well insulated attic floor or cathedral ceiling to keep attic air and roof surface cold (below freezing) to prevent warm spots on roof which lead to snow melting (2, 33).

b. Maintain a well sealed ceiling air barrier to prevent warm air from leaking into the attic (2, 33).

c. Ventilate the attic or cathedral ceiling to keep the inside face of the sheathing cold in winter (2, 33).

d. Install a waterproof membrane under the roofing on the lower portion of the roof (above the eaves). This will not prevent damming, but will inhibit water from backing up under the shingles (2, 33).

e. Other less effective and less practical methods (often with other drawbacks) to mitigate ice damming or its effects include: electric heating cables, removing gutters, eliminating roof overhangs, ice pick, and salting the eave/gutter (2).

B.3.3 Design Options

Option 1: Ventilated attic with insulation in ceiling. Ducts under floor. Vapor retarder in ceiling.

This configuration is the standard practice for attic design in multi-section manufactured homes. The literature suggests that ventilating the attic in this climate is not advisable from a moisture control or energy conservation standpoint.

Hypothesis	Literature
Moisture is allowed to leave the home via ventilation air movement out of attic.	This is contradicted by the literature. No scientific sources have been found to support this hypothesis. More moisture enters attic, and potentially the home, with humid outside air, than is vented from attic. (3, 5, 13, 14, 15, 23, 24)
Attic ventilation reduces the interior temperature of the attic in cooling season.	Supported by the literature. A reduction of approximately 15 to 20 degrees F can be expected during peak cooling season with typical 1 to 150 or 1 to 300 ventilation ratios (26).
Lower attic temperature reduces the cooling load on the home.	For homes with a well insulated ceiling, the load increase is minor (20, 24, 25, 33). The load may actually increase with the increased latent cooling load of more humid air entering the attic and leaking into the living space (20, 24). Cool attic temperatures are of more significance for poorly insulated (<R14) ceilings (29).
Lower attic temperature keeps shingles cool in cooling season.	The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. (15, 23, 26, 33)

Option 2: Ventilated attic with insulation in ceiling. Vapor retarder in ceiling. Ducts in attic covered with insulation.

The literature suggests that ventilating the attic in this climate is not advisable from a moisture control standpoint. Locating ducts in the attic is advantageous from an energy standpoint if they are better covered with insulation than they would be under the floor. If not well insulated, the cool duct may precipitate condensation on its surface.

Hypothesis	Literature
Moisture is allowed to leave the home via ventilation air movement out of attic.	This is contradicted by the literature. No scientific sources have been found to support this hypothesis. More moisture enters attic, and potentially the home, with humid outside air, than is vented from attic. (3, 5, 13, 14, 15, 23, 24)
Attic ventilation reduces interior temperature of attic in cooling season.	Supported by the literature. A reduction of approximately 15 to 20 degrees F can be expected during peak cooling season with typical 1 to 150 or 1 to 300 ventilation ratios (26).
Duct is under insulation and therefore less prone to condensation and energy loss	The effectiveness of this insulation coverage should be investigated.
Lower attic temperature reduces cooling load on home.	For home with a well insulated ceiling, the load increase is minor (20, 24, 25, 33). The load may actually increase with the increased latent cooling load of more humid air entering the attic and leaking into the living space (20, 24). Cool attic temperatures are of more significance for poorly insulated (<R14) ceilings (29).
Lower attic temperature keeps shingles cool in cooling season.	The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. (15, 23, 26, 33)

Option 3: Sealed (unvented) attic with insulation in ceiling. Ducts under floor. No vapor retarder in ceiling.

The literature suggests that eliminating the ventilation from current attic design practice will reduce moisture levels in the attic and that adverse effects on energy use and shingle lifespan will be minimal. This configuration has the potential to lower costs and improve performance in cool/humid climates, and should be explored further.

Unvented attics used in the cool/humid climate must account for the possibility of roof leaks, wind driven rain, snow/ice dams due to thermal shorts in insulation and reduced dry out potential if it gets wet. Unvented attics in cool-humid climates would require additional design considerations, but may provide significant advantages.

Hypothesis	Literature
Humid outside air cannot enter the attic and contribute to increasing the moisture level.	Supported by the literature (3, 5, 13, 14, 15, 23, 24).
In cooling season, moisture in the attic will migrate via vapor diffusion through the ceiling insulation and dry towards the interior.	Supported by the literature (7, 13).
Cooling load not detrimentally impacted by higher temperature in attic (assuming adequate ceiling insulation).	For home with a well insulated ceiling, the load may actually increase with the increased latent cooling load of more humid air entering the attic (20, 24, 25, 33).
Minor increase in shingle temperature is not a	The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat

Hypothesis	Literature
significant disadvantage of this design.	exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

Option 4: Sealed (unvented) attic with insulation in ceiling. Ducts in ceiling. Vapor retarder in ceiling.

The literature suggests that eliminating the ventilation from current attic design practice will reduce moisture levels in the attic and that adverse effects on energy use and shingle lifespan will be minimal. This configuration has the potential to lower costs and improve performance in cool/humid climates where ducts are already placed in the attic, and should be explored further. This configuration is an improvement over option 3 from an energy standpoint, if ducts will be better insulated and further removed from ground moisture than they would be in the floor.

Hypothesis	Literature
Humid outside air cannot enter the attic and contribute to increasing the moisture level.	Supported by literature (3, 5, 13, 14, 15, 23, 24).
Moisture in attic insulation will migrate via vapor diffusion through the ceiling insulation and dry towards the interior.	Supported by literature (7, 13). Further research is needed to determine if this mechanism is sufficient to eliminate all excess moisture from the attic.
Cooling load not detrimentally impacted by higher temperature in attic (assuming adequate ceiling insulation).	For home with a well insulated ceiling, the load increase is minor (20, 24, 25, 33). The load may actually increase with the increased latent cooling load brought on by more humid air entering attic. (20, 24). Cool attic temperatures are of more significance for poorly insulated (<R14) ceilings (29).
Minor increase in shingle temperature is not a significant disadvantage of this design, especially in cooler climates with less annual sunshine.	The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

Option 5: Sealed (unvented) attic with insulation following the roof plane. Ducts under floor.

The literature suggests that this design is beneficial from a moisture control standpoint.

Hypothesis	Literature
Humid outside air cannot enter the attic and contribute to increasing the moisture level.	Supported by the literature (3, 5, 13, 14, 15, 23, 24)
Conditioning of attic air (now that it is included inside the thermal envelope) will keep its relative humidity level down and minimize the opportunity for condensation.	Supported by the literature (23, 26, 33). Further research is needed to determine if attic surfaces will be kept warm enough to prevent staining and condensation during heating season.

Minor increase in shingle temperature is not a significant disadvantage of this design, especially in cooler climates with less annual sunshine.	The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

Option 6: Sealed (unvented) attic with insulation following the roof plane. Ducts in attic.

The literature suggests that this design is beneficial from a moisture and energy standpoint.

Hypothesis	**Literature**
Humid outside air cannot enter the attic and contribute to increasing the moisture level.	Supported by the literature (3, 5, 13, 14, 15, 23, 24).
Conditioning of attic air (now that it is included inside the thermal envelope) will keep its relative humidity level down and minimize the opportunity for condensation. During heating season, attic condensation surfaces will be kept warmer – above the dew point.	Supported by the literature (23, 26, 33). Literature suggests that ventilation chutes between sheathing and insulation are beneficial by removing moisture and slight cooling (33).
The energy performance of the home will be enhanced as ducts will not conduct or leak air to the outside, nor will ducts draw moist air inside from crawlspace.	Supported by the literature (18, 22, 24, 25, 26, 28).
Minor increase in shingle temperature is not a significant disadvantage of this design, especially in cooler climates with less annual sunshine.	The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

B.4 MIXED AND COLD CLIMATE

B.4.1 Summary

A number of studies claim that attic ventilation is one effective strategy to prevent condensation in the roof cavity. However, other strategies such as lowering humidity in the home and carefully sealing the air/vapor retarder in the ceiling are more effective (5, 7, 20, 33). A vapor retarder and air barrier is recommended in the ceiling of ventilated and unventilated attics to prevent humid air from the home from infiltrating into the attic space (5, 7, 13). An unvented, cathedralized attic with rigid foam insulation on the roof deck is an acceptable design (15, 23, 33). Cold air can hold only limited amounts of moisture. Homes in severe cold climates, with well-insulated ceilings may not transmit enough heat into the attic to warm the attic air enough to carry away much moisture (13), thereby limiting the value of attic ventilation.

B.4.2 Design Parameters

The goals to be achieved through changes in the ventilation strategy and suggested approaches for mixed and cold climates as derived from the literature references are summarized below in approximate order of effectiveness.

Prevent condensation in attic that might lead to moisture problems. This is a problem during the winter months in this climate.

a. Apply foam insulation, which is relatively vapor impermeable, to the underside of the roof sheathing (33).

b. Dehumidify the living space to remove moisture from the home before it reaches the ceiling air/vapor barrier (7, 33).

c. Create a tightly sealed air/vapor barrier in the ceiling to prevent moisture generated in the living space from entering the attic (5, 7, 33). Achieving and maintaining the necessary level of sealing may be difficult throughout the manufactured home production transportation and installation processes.

d. Keep the attic temperature warm enough to prevent surfaces from falling below dew point temperature – via insulation on the roof deck instead of the attic floor (15, 23).

e. Ventilate the attic or cathedral ceiling to dilute moisture once it passes into the attic (5, 7, 33). This is less effective in severe cold climates with well insulated ceilings since cold air can carry away little moisture (2, 13).

Minimize energy consumed by heat transfer through attic space or ductwork in attic.

a. Create a well sealed air barrier in the ceiling to prevent conditioned air from escaping into unconditioned attic (if the attic is ventilated).

Maintain durability of roofing and sheathing materials. Degradation of roofing materials can lead to higher replacement cost as well as leaks and their associated problems.

a. Same approaches as other climates (non-asphalt or light colored roofing, or attic ventilation), but impact is less significant since high temperatures are less extreme and of shorter duration in this climate.

Prevent ice dams, which can lead to hazardous conditions as well as leaks and their associated problems.

a. Construct a well insulated attic floor or cathedral ceiling to keep attic air cold (below freezing) to prevent warm spots on roof which lead to snow melting (2, 33).

b. Maintain a well sealed ceiling air barrier to prevent warm air from leaking into attic (2, 33).

c. Install a waterproof membrane under the roofing on the lower portion of the roof (above the eaves). This will not prevent damming, but will prevent water from backing up under the shingles (2, 33).

d. Ventilate the attic or cathedral ceiling to keep the inside face of the sheathing cold in winter (2, 33).

e. Other less effective and less practical methods (often with other drawbacks) to mitigate ice damming or its effects include electric heating cables, removing gutters, eliminating roof overhangs, ice pick, and salting the eave/gutter (2).

B.4.3 Design Options

Option 1: Ventilated attic with insulation in ceiling. Ducts under floor. Vapor retarder in ceiling.

This configuration is the standard practice for attic design of multi-section manufactured homes. Most of the literature agrees that ventilation is a moderately effective means of removing moisture from the attic during winter months (except in sever cold climates with well insulated ceilings), however the most effective means is to reduce the humidity in the living area. Ventilation may also provide some benefit in prolonging asphalt shingle lifespan, by keeping the attic cavity at a lower temperature.

Hypothesis	Literature
Moisture is allowed to leave the home via ventilation air movement out of the attic.	Some support from the literature (5, 7, 33) as a secondary method. However, in winter, cold air can carry little moisture out of the attic (2, 13). Recent studies have shown that attic relative humidity levels are not affected by attic ventilation. (1, 8)
Attic ventilation reduces the interior temperature of the attic in cooling season.	Supported by the literature. A reduction of approximately 15 to 20 degrees F can be expected during peak cooling season with typical 1 to 150 or 1 to 300 ventilation ratios (26).
Lower attic temperature reduces the cooling load on the home.	For homes with a well insulated ceiling, the load increase is minor (20, 24, 25, 33). Cool attic temperatures provide a more significant advantage in homes with poorly insulated (<R14) ceilings (29).
Lower attic temperature keeps shingles cool in cooling season.	Even in hot climates the effect is minimal. The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

Option 2: Ventilated attic with insulation in ceiling. Duct in attic covered with insulation. Vapor retarder in ceiling.

Most of the literature agrees that ventilation is a moderately effective means of removing moisture from the attic during winter months; however the most effective means is to reduce the humidity in the living area. Ventilation may also provide some benefit by prolonging asphalt shingle lifespan. Locating the ducts in the attic conserves energy if it will be better insulated than if it were in the floor. If not well insulated, the cool duct may precipitate condensation on its surface.

Hypothesis	Literature
Moisture is allowed to leave the home via ventilation air movement out of the attic.	Some support from the literature (5, 7, 33) as a secondary method. However, in winter, cold air can carry little moisture out of the attic (2, 13). Recent studies have shown that attic relative humidity levels are not affected by attic ventilation. (1, 8)
Attic ventilation reduces the interior temperature of the attic in cooling season.	Supported by the literature. A reduction of approximately 15 to 20 degrees F can be expected during peak cooling season with typical 1 to 150 or 1 to 300 ventilation ratios (26).
Lower attic temperature reduces the cooling load on the home.	For homes with a well insulated ceiling, the load increase is minor (20, 24, 25, 33). Cool attic temperatures provide a more significant advantage in homes with poorly insulated (<R14)

	ceilings (29).
Duct is under insulation and therefore immune to condensation and energy loss.	The effectiveness of this insulation coverage should be investigated.
Lower attic temperature keeps shingles cool in cooling season.	Even in hot climates the effect is minimal. The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

Option 3: Sealed (unvented) attic with insulation in ceiling. Vapor retarder in ceiling. Ducts under floor.

This configuration will result in condensation in the attic unless the air/vapor barrier is 100% intact. It is unrealistic to expect a perfect air/vapor barrier and so an outlet must be provided for moisture to exit the attic or condensation will form on roof sheathing (5, 7).

Option 4: Sealed (unvented) attic with insulation in ceiling. Ducts in attic. Vapor retarder in ceiling.

Like option 3, this configuration will result in condensation in the attic unless the air/vapor barrier is 100% intact, an unreasonable expectation.

Option 5: Sealed (unvented) attic with insulation following the roof plane. Ducts under floor. Vapor retarder in roof plane.

To control moisture within the roof cavity in this configuration either, a) an intact ceiling vapor barrier must be maintained (through the use of closed-cell foam insulation under to roof), b) the roof cavities must be vented with foam air chutes, or c) rigid deck insulation to keep sheathing within the thermal envelope must be used. Most literature discussing this configuration advocates option (c).

Hypothesis	Literature
Conditioning/heating of attic air (now that it is included inside the thermal envelope) will keep its relative humidity level down and minimize the opportunity for condensation.	Supported by the literature (14, 26, 33).
During heating season, attic condensation surfaces (including the 1st condensation surface – the inside surface of the sheathing) will be kept warmer – above dew point.	An unvented, cathedralized attic with rigid foam insulation on the roof deck is an acceptable design (15, 23, 33).
Minor increase in shingle temperature is not a significant disadvantage of this design, especially in cooler climates with less annual sunshine.	Even in hot climates the effect is minimal. The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).

Option 6: Sealed (unvented) attic with insulation following the roof plane. Ducts in attic.

To control moisture within the roof cavity in this configuration either, a) an intact ceiling vapor barrier must be maintained (through the use of closed-cell foam insulation under to roof), b) the roof cavities can be vented with foam air chutes, or c) rigid deck insulation to keep sheathing within the thermal envelope may be used. Most literature discussing this configuration advocates option (c). Locating the duct in the attic will result in superior energy performance compared to option 5, assuming that the insulation of the duct would be superior than if located in the floor.

Hypothesis	Literature
Conditioning/heating of attic air (now that it is included inside the thermal envelope) will keep its relative humidity level down and minimize the opportunity for condensation.	Supported by the literature (14, 26, 33).
During heating season, attic condensation surfaces (including the 1st condensation surface – the inside surface of the sheathing) will be kept warmer – above dew point.	An unvented, cathedralized attic with rigid foam insulation on the roof deck is an acceptable design (15, 23, 33).
Minor increase in shingle temperature is not a significant disadvantage of this design, especially in cooler climates with less annual sunshine.	Even in hot climates the effect is minimal. The literature estimates an increase of 3 to 5 degrees F on average. The underside of roof sheathing is a poor heat exchanger, so the temperature of the shingles is not greatly affected by the temperature of the attic air. Lighter colored shingles are a more effective way of keeping them cooler (15, 23, 26, 33).
Energy performance of the home will be enhanced as ducts will not conduct or leak air to the outside, nor will ducts draw moist air inside from crawlspace	Supported by the literature (18, 22, 24, 25, 26, 28)

C

SUMMARY OF THE LITERATURE

The literature explains that ventilation of attic and cathedral ceiling air cavities has been promulgated for four reasons: moisture control, energy conservation, asphalt shingle durability, and ice dam prevention. The research that led to the attic ventilation paradigm was predicated on a cold climate. U.S. building codes, including the HUD-code, require attic ventilation in most cases for all climates. The literature suggests that optimal roof system design may vary significantly by climate.

Sealing the attic from ventilation, with the insulation either in the ceiling or the roof plane, may provide advantages from a moisture control standpoint in hot/humid and cool/humid climates. Sealing the attic in hot/dry climates does not provide any significant advantages for HUD-code homes unless it provides for improved insulation of ductwork located in the attic.

Elimination of ventilation leads to higher attic air and surface temperatures. The effect of these higher temperatures on asphalt shingle durability is unknown, although certain shingle manufacturers void or reduce their warranties if their shingles are installed over unvented roofs.

Control of attic moisture in mixed and cold climates can best be achieved through: 1) reduction of humidity in the living space during winter; 2) a well-sealed ceiling air barrier and vapor retarder; 3) attic ventilation. The amount of moisture removed via attic ventilation in cold climates in winter is limited, as cold air has little moisture-carrying capacity. However, the degree to which a reduction in humidity in the home and air movement across the ceiling plane can be achieved is uncertain, so ventilation of the attic provides a relief valve should moisture get into the attic. It also keeps the attic cooler in summer, potentially providing energy benefits.

1. "Attic Ventilation and Moisture Control Strategies." Ottawa: Canada Mortgage and Housing Corporation, 1997. Prepared by Sheltair Scientific Ltd.

Four homes with unvented attics and four similar control homes with vented attics (in Edmonton and Vancouver, Canada) were monitored for moisture levels, humidity, and temperature. Lack or presence of attic ventilation did not correlate to large reductions or increases in moisture levels. Homes with higher indoor humidity had higher attic moisture levels irrespective of attic ventilation or attic-house interface air leakage rates.

2. "Attic Venting, Attic Moisture, And Ice Dams." Canada Mortgage and Housing Corporation, 1999, at *www.cmhc-schl.gc.ca*.

Recommendations for combating roof leaks, attic moisture and ice dams in cold climates. Attic ventilation is overrated in its ability to remove moisture, since cold air cannot carry much moisture. Ice dams can be prevented by eliminating heat sources and air leaks in the attic.

3. Bailey, R., Bailey Engineering Corp., 1998. "Attic Ventilation in Humid Climates: Benefit or Liability?" Today's A/C and Refrigeration News, IAQ Technical Report January 1998.

Attic ventilation in coastal climates can create more problems then benefits, largely due to humidity of outside air (also salt). The author has eliminated attic ventilation from many homes without adverse affect, and in many cases with improvements in conditions.

4. Burch, D., 1995. "Analysis of moisture accumulation in the roof cavities of manufactured housing." ASTM Special Technical Publication, n1255, Sep, 1995. Building and Fire Research Lab, National Institute of Standards and Technology, Gaithersburg, MD, USA.

A detailed computer analysis is conducted to investigate whether moisture problems occur in the roof cavity of manufactured homes constructed in compliance with the current Department of Housing and Urban Development (HUD) Standards for manufactured housing. The current HUD Standards require a ceiling vapor retarder, but do not require outdoor ventilation of the roof cavity. In cold climates, the analysis revealed that moisture accumulates at lower roof surface and poses a risk of material degradation. The analysis found the following combination of passive measures to be effective in preventing detrimental winter moisture accumulation at lower surface of the roof: 1) providing a ceiling vapor retarder, 2) sealing penetrations and openings in the ceiling construction, and 3) providing natural ventilation openings in the roof cavity. In addition, the performance of a roof cavity exposed to a hot and humid climate is investigated. The analysis revealed that outdoor ventilation of the roof cavity causes the monthly mean relative humidity at the upper surface of the vapor retarder to exceed 80%. This condition is conductive to mold and mildew growth.

5. Burch, D.M., 1992. "Controlling Moisture in the Roof Cavities of Manufactured Housing." NISTIR 4916, Building and Fire Research Laboratory, Building Environment Division, National Institute of Standards and Technology, Gaithersburg, MD.

Computer analysis with current HUD standards, ceiling vapor retarder, no attic ventilation: (1) In cold climate, moisture occurs at lower roof sheathing surface, posing risk of degradation. In winter a ceiling vapor retarder, sealing penetrations, and passive venting of attic are effective solutions (2) In hot and humid climate, venting of attic to outside results in unacceptably high humidity levels at upper surface of vapor retarder, thereby inducing mold).

6. Burch, D.M., Thornton, B.A., Tsongas, G.A., and Walton, G.N., 1997. "A Detailed Computer Analysis of the Moisture Performance of Roof Constructions in The U.S. DOE Moisture Control Handbook." Proceedings of the Fourth International Symposium on Roofing Technology, Sept. 17-19, 1997, Gaithersburg, MD. Proceedings. National Roof Construction Association. Nov. 1997.

Mathematical model (MOIST Attic Model) used to predict moisture performance of 15 current-practice site-built designs. Sealing roof vents in cold climates resulted in fibre saturation of the plywood. Humidification of the living space made conditions even worse. Sealing ceiling air leakage has only a minor effect on attic humidity. In mixed and hot/humid climates, attic ventilation and ceiling vapor retarders are detrimental from a moisture standpoint.

7. Burch, D.M., Tsongas, G.A. and Walton, G.N., September 1996. "Mathematical Analysis of Practices to Control Moisture in the Roof Cavities of Manufactured Houses." NISTIR 5880, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, MD.

Mathematical Model applied to cold climate (unless noted), for a double-section HUC-code home: (1) airflow from house to attic was dominant moisture transport mechanism – not water-vapor diffusion (2) houses with high humidity had high roof sheathing moisture content (3) passive roof vents (1/300 rule) maintained roof sheathing moisture content below saturation in non-humidified houses in winter

(4) mechanical attic ventilation rate for removing moisture in winter was too low (5) ceiling vapor retarder provided small reductions in roof sheathing moisture content (6) interior ceiling vapor retarder in a/c house in hot and humid climate had RH above 80%, inducing mold (7) ceiling vents for whole-house ventilation in cold climates substantially increased roof sheathing moisture content in unvented attic

8. Forest, T.W., and Walker, I.S., 1993. "Attic Ventilation and Moisture." Final Report. Ottawa: Canada Mortgage and Housing Corporation.

Computer model simulations of homes in wet coastal climates in Canada. High attic ventilation rates resulted in higher sheathing moisture content than did lower ventilation rates. Higher ventilation rates produced colder attics without sufficiently lowering attic water vapor pressure, resulting in high attic RH and moisture content in sheathing.

9. Fugler, D.W., 1999. "Conclusions from Ten Years of Canadian Attic Research." ASHRAE Transactions: Symposia, CH-99-11-1.

A number of studies, including testing and modeling were conducted from 1988-1997 in Canada. The ATTIX model was develop and compared to test results. Ventilated and sealed attics were compared in a variety of Canadian climates. Conclusions include:

a. Natural ventilation of attics is largely dependent on wind speed. The effects of attic ventilation on wood moisture content will vary by climate. In coastal areas, minimizing attic ventilation rates may lower attic wood moisture contents.

b. Minimizing heat and moisture flows from the house to the attic is a prudent way of reducing ice damming and attic moisture problems.

c. There is no compelling case to modify Canadian attic ventilation code requirements (1:300), however codes should permit design flexibility to allow alternatives in controlling attic moisture levels.

10. Goldberg, L.F., Huelman, P.H. and Bridges, B.B., 1999. "A Preliminary Experimental Assessment of the Comparative Thermal Performance of Attics and Cathedral Ceilings in a Cold Climate."

The paper describes the results from monitoring of a research building in Minnesota with 12 bays with a variety of roof, wall and floor constructions. Relevant preliminary results (the months of March and April) are as follows:

a. Unvented attics and cathedral ceilings show a higher thermal integrity than their vented counterparts, but the penalty is less for attics than for cathedral ceilings.

b. Vented attics perform better than vented cathedral ceilings for the same framing type.

11. Graham, Mark S., National Roofing Contractors Assoc., 2001. "Principles of Attic Ventilation." From Professional Roofing January 2001.

Attic ventilation is required by most building codes, however this is increasingly being questioned. ASHRAE 1997 states that venting should be an option for hot-humid climates, while continuing to recommend it for cool climates. NRCA recommends balanced venting As additional research is brought forward, they will re-evaluate as appropriate.

12. Hens, H. and Janssens, A., 1999. "Heat and Moisture Response of Vented and Compact Cathedral Ceilings: A Test House Evaluation." ASHRAE Transactions: Symposia, CH-99-11-3.

Field tests of site-built homes in Europe were conducted. The researchers drew the following conclusions:

a. The consequences of air ingress and wind-washing for the hygrothermal performance and durability of well-insulated cathedral ceilings are negative; there is worse thermal performance, problematic moisture response, and degraded durability.

b. A vented airspace above the insulation is not effective in humid, cool climates for preventing concealed condensation.

c. A vapor retarder is only efficient if air tightness is guaranteed.

13. Lstiburek, J.W. "Ceiling Vapor Barrier Debate." Building Science Corp., at *www.buildingscience.com*.

Plastic vapor barriers should only be installed in vented attics in climates with more than 8,000 heating degree days. Vapor retarders (kraft faced insulation or latex ceiling paint) should be used in all other climates except hot-humid or hot-dry climates. In hot-humid climates, attics should not be vented and vapor retarders should not be installed on the interior of assemblies. In hot-dry climates a vapor retarder should also not be installed, but attics can be vented. All vented and unvented attics should have an air barrier regardless of climate.

14. Lstiburek, J.W. "Vented Attics in the South." Building Science Corp., at *www.buildingscience.com*.

Venting attic in hot/humid climates will cause moisture problems. Unvented attic with insulation following roof plane is preferable.

15. Lstiburek, J.W., 1999. "Unventing Attics in Cold Climates / Unvented Attic Discussion." Home Energy Magazine Online Nov./Dec. 1999.

In humid climates, venting attics brings moisture into the structure. In cold climates, venting attics brings in snow. In roofs with complex geometries, venting roof assemblies and installing air barriers can be difficult. Even in hot-dry climates not venting attics can make sense. Unvented "cathedralized" roofs save on cooling load in hot climates (ducts do not leak or conduct to the outside) and reduce moisture problems in hot/humid climates. In cold climates, use rigid foam insulation on roof deck to eliminate moisture problems. Trade-off is 2-3 yrs shorter life of asphalt shingles.

16. U.S. Department of Housing and Urban Development. 1999. Code of Federal Regulations: Title 24, Part 3280, Manufactured Home Construction and Safety Standards.

See quoted text in paper.

17. Parker, D.S. and Sherwin, J.R., June 1998. "Comparative Summer Attic Thermal Performance of Six Roof Constructions." FSEC-PF-337-98, Florida Solar Energy Center, Cocoa, Florida. Presented at The 1998 ASHRAE Annual Meeting, June 20-24, 1998, Toronto, Canada.

Florida Solar Energy Center (FSEC) measured summer attic thermal performance of six roofs at a heavily instrumented test site, the Flexible Roof Facility (FRF). The FRF is a 1,152 square foot (107

m2) building with six roof adjacent test cells which are heavily insulated from each other. Data were obtained during summer on: temperature, meteorological conditions, surface and tower wind speeds, attic humidity, and roof surface moisture accumulation. Cooling season thermal performance of roofing systems were compared. Six differing roof types were evaluated with variations in color, ventilation, roof mass and the use of radiant barrier systems (RBS). The tests show that roof system reflectivity greatly influences attic summer temperatures. Two white roofing systems outperformed the other options. Another large improvement comes from greater roof mass; tiled roofs performed better than those with asphalt shingled roofs. An increased attic ventilation rate improved the effectiveness of an attic radiant barrier. Of the evaluated options, white tile roof best controlled attic heat gain.

18. **Parker, D.S., Sonne, J.K., Sherwin, J.R. and Moyer, N., November 2000. "Comparative Evaluation of the Impact of Roofing Systems on Residential Cooling Energy Demand in Florida." Contract Report FSEC-CR-1220-00, Florida Solar Energy Center, Cocoa, FL.**

Roof and attic thermal performance exert a powerful influence on cooling energy use in Florida homes. Unshaded residential roofs are heated by solar radiation causing high afternoon attic air temperatures. The large influence on cooling is due to increased ceiling heat transfer as well as heat gains to the duct systems which are typically located in the attic space. The Florida Power and Light Company and the Florida Solar Energy Center instrumented six side-by-side Habitat homes in Ft. Myers, Florida with identical floor plans and orientation, R-19 ceiling insulation, but with different roofing systems designed to reduce attic heat gain. A seventh house had an unvented attic with insulation on the underside of the roof deck rather than the ceiling.

19. **Roodvoets, David L., 2001, "Practical Implications of the Elimination of Natural Attic Ventilation in Mixed Climates." Performance of Exterior Envelopes of Whole Buildings VIII Conference Proceedings (ASHRAE), Florida, December 2001.**

Many attics are retrofitted with additional ventilation, primarily ridge ventilation, when the roof covering is replaced. The driving forces for this action are usually the presence of mold, wet insulation, wet or weakened wood, or the premature aging of the roof coverings. A protocol for determining the effects of the added ventilation is developed. Several occupied whole buildings are surveyed to determine the reasons the ventilation was added and to establish a base for determining the outcome of the additional ventilation.

20. **Rose, W.B., 1995. "History of Attic Ventilation Regulation and Research, The." Thermal Performance of the Exterior Envelopes of Buildings VI Conference Proceedings (ASHRAE), December 1995.**

The 1:300 attic ventilation rule was not supported by the research at time of the rule's implementation. Ventilation of well-insulated attics does not significantly affect cooling load.

21. **Rose, W.B., 1992. "Measured Values of Temperature and Sheathing Moisture Content in Residential Attic Assemblies." Thermal Performance of the Exterior Envelopes of Buildings V, Proceedings of ASHRAE/DOE/BTECC/CIBSE Conference, Clearwater Beach, FL, 7-10 Dec. 1992, 379-390.**

An attic test facility with 8 bays of various configurations was constructed in Illinois. Heat transfer, moisture movement and airflow were measured continuously for 2 years. Conclusions include:

a. Ventilation keeps attics cooler

b. Vented flat and cathedral ceilings maintain temperatures and moisture in a moderate range, even with a small opening in the ceiling

c. Flat-ceiling attics with no ceiling penetrations showed little difference in moisture content whether vented or not.

d. Cathedral ceilings with penetrations showed significant moisture effects

22. Rudd, A.F., September, 1999. "Performance of Building America Initiative Houses with Unvented Attics and Tile Roofs Constructed by Pulte Homes, Las Vegas Division," at *www.buildingscience.com*.

Both energy modeling and field testing reveal no energy penalty for unvented attics in a hot climate. Differences associated with tile versus asphalt roofing shingles are also discussed.

23. Rudd, A.F., "Unvented Roof Systems." Building Science Corp., at *www.buildingscience.com*.

Unvented roofs are preferable and have been designed for hot/dry and hot-humid climates. They have also been designed for cold and mixed climates, where rigid deck insulation is required. In these types of unvented roof assemblies, interior vapor barriers are not recommended as these assemblies are expected to be able to "dry" towards the interior. Unvented roofs can be safely used in hot climates. In hot-humid climates an unvented roof decreases the migration of moisture laden air into the building. Although tile roofs are more effective in reducing cooling loads, asphalt shingle roofs can be used even when the roof is unvented in hot climates.

24. Rudd, A.F., Lstiburek, J.W., 1997. "Vented and Sealed Attics In Hot Climates." Presented at the ASHRAE Symposium on Attics and Cathedral Ceilings, Toronto, June 1997. ASHRAE Transactions TO-98-20-3.

Sealed attic construction, by excluding vents to the exterior, can be a good way to exclude moisture laden outside air from attics and may offer a more constructible alternative for air leakage control [this study based on a wood frame ranch house on slab]. Sealed attic, "cathedralized", construction can be done without an associated energy penalty in hot climates.

25. Rudd, A.F., Lstiburek, J.W., Kohta, U., 2000. "Unvented-Cathedralized Attics: Where We've Been and Where We're Going." ACEEE Proceedings, August, 2000, at *www.buildingscience.com*.

Unvented, cathedralized attics are recommended for hot climates to decrease cooling loads in homes with ducts in attics. Results from test houses are presented in detail.

26. Rudd, A.F., Lstiburek, J.W. and Moyer, N.A., 1996. "Measurement of Attic Temperature and Cooling Energy Use in Vented and Sealed Attics in Las Vegas, NV." EEBA Excellence, The Journal Of The Energy Efficient Building Association, Spring 1997. Energy Efficient Building Association, Minneapolis, MN. (also summarized in Home Energy Mag. May/June 97: Conditioned Attics Save Energy in Hot Climates).

"Cathedralized" attic houses had less air leakage than the 1:150 vented attic house, and had cooling energy savings. Tile-top temps increased a maximum of 3 deg F. Plywood roof sheathing increased a maximum of 17 deg. F.

27. Samuelson, I., 1992. "Moisture Control in a Ventilated Attic." Thermal Performance of the Exterior Envelopes of Buildings V, Proceedings of ASHRAE/DOE/BTECC/CIBSE Conference, Clearwater Beach, FL, 7-10 Dec. 1992, 512-516.

Calculations and measurements were made of a ventilated roof in a cold climate (Sweden). The researchers make the following conclusions:

a. Additional insulation added to the roof deck results in a slight improvement of the moisture performance.

b. An unventilated roof space, to which there are no "external" inputs of moisture, will have a considerably better mean microclimate, especially for climates with cold, damp nights and warm days.

c. These results presume no air leakage from the house as is typical of Swedish homes, which are built very tight and have a slightly negative indoor air pressure.

28. Siegel, J., Walker, I. and Sherman, M., 1999. "Delivering Tons to the Register: Energy Efficient Design and Operation of Residential Cooling Systems." Lawrence Berkeley National Laboratory.

Field measurements and simulation results show that houses with ducts located in "cathedralized" attics have dramatically increased cooling performance and energy savings compared to homes with ducts in vented, uninsulated attics.

29. Stewart, B.R., "Attic Ventilation for Homes." Texas AandM Univ., Ag. Ext. Service.

Ventilation of attic is important to remove heat and moisture. Ventilation quantities and methods are discussed.

30. 2001 ASHRAE Handbook, Fundamentals, American Society of Heating, Refrigeration and Air Conditioning Engineers, Atlanta, GA (Chapter 24).

See quoted text in paper.

31. TenWolde, Anton. 1997. "FPL Roof Temperature and Moisture Model." FPL roof temperature and moisture model: description and verification. Res. Pap. FPL-RP-561. Madison, WI: U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory. 48 p.

Mathematical model to predict attic temperatures, relative humidities, roof sheathing moisture content. The paper evaluates the accuracy of the model by comparing it with measured data.

32. TenWolde, A. and Burch, D.M., 1993. "Ventilation, Moisture Control, and Indoor Air Quality in Manufactured Houses: A Review of Proposed Changes in the HUD Standards and a Proposal for Revised Standards." U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI and Burch, Douglas M. U.S. Dept. of Commerce, National Institute of Standards and Technology, Gaithersburg, MD.

FPL/NIST proposed revisions of 3280.504(c):

The authors' preferred option: Ventilation of roof cavity optional.

The authors' alternative recommendation:

Roof cavities in regions 3 and 4 to have minimum free vent area of at least 1/300 of floor area, 50-60% of which shall be in the upper portion of the space. Or, a mechanical system with minimum capacity of 0.02 cfm per sf attic floor area with intake of at least 1 sf per 300 cfm fan capacity. Cathedral ceilings are not required to have roof ventilation.

MOIST computer model demonstrates benefit of reduction of living space humidity, attic ventilation and ceiling vapor/air barrier in ceiling, in reducing attic moisture.

33. TenWolde, A., Rose, W.B., "Issues Related to Venting of Attics and Cathedral Ceilings." ASHRAE Transactions 1999, V. 105, Pt. 1.

Attic ventilation should not be the principal strategy to control moisture problems, etc. in the attic: (1) indoor humidity control should be primary means to limit moisture in attics (2) to minimize ice dams, heat sources and warm air leakage into attic should be minimized (3) vent attics in cold and mixed climates (4) unvented cathedral ceilings can perform satisfactorily in cold and mixed climates if cavity is insulated, indoor humidity is controlled, air leakage minimized, and ceiling vapor retarder is installed (5) ventilation should be optional in wet coastal and hot/humid climates.

34. Terrenzio, L.A., Harrison, J.W., Nester, D.A., and Shiao, M.L., Natural Vs. Artificial Aging: Use of Diffusion Theory to Model Asphalt and Fiberglass-Reinforces Shingle Performance 1997, Proceedings of the Fourth International Symposium on Roofing Technology, Sept. 17-19, 1999, Gaithersburg, MD.

The data suggest the primary effect of heat in initiating and promoting degradation of Asphalt-based roofing shingles.

35. Zieman, M.L., and J.D., 1984. "Waldman, Moisture Problems in Mobile Homes." RADCO, Inc., Gardena, CA. Prepared for HUD under contract H-10992.

Survey of 59 existing MH with moisture problems in 5 regions. Attic condensation problems are believed to be caused by low indoor ventilation rates, particularly inadequate ventilation of roof cavities.